Engineering Case Library

ECL-173A

THE CRYOGENIC METER (A)

A study of the design, development, and testing of a positive displacement cryogenic meter for metering liquid oxygen and nitrogen. The meter was needed to replace the existing metering method which resulted in losses of up to 10% of the fluids being metered.

 Prepared for the Engineering Case Program by Mr. H. C. Kornemann with support from the National Science Foundation.

THE CRYOGENIC METER (A)

During the late 1930s the availability of liquid oxygen pumps, which were capable of pumping to 350 psi discharge pressure, made it possible to improve liquid oxygen distribution systems by pumping directly into the customer's cold converters (i.e., his storage tank) while they were being operated at pipeline pressures of 150 to 200 psi. Previously, because liquid oxygen pumps were not available, it was necessary to blow down the pressure in the cold converters to atmospheric pressure before filling them with low pressure liquid oxygen. The amount delivered was determined by the known volume of the customer's cold converters when filled to a calibrated try-cock.

The Linde Company, a division of Union Carbide Corporation, recognized the need for a positive displacement cryogenic meter for metering liquid oxygen and nitrogen. An accurate meter with a 50 gpm capacity and a 300 psi W. P. having low pressure drop and high accuracy was needed. The meter had to be safe, simple, lightweight, rugged, low in cost and suitable for both stationary and truck operation.

The use of such a liquid oxygen meter to fill cold converters under pipeline pressure would reduce the direct filling loss by a factor of 10, simplify and significantly decrease the filling time, double the customer's effective liquid oxygen storage capacity under pipeline pressure and make possible larger individual liquid oxygen deliveries without adding extra cold converters.

Liquid oxygen measurement then commercially available was by any one of three methods:

- By use of a calibrated try-cock. This method was used for customers who had cold converters operating at 150 psi pipeline pressure. After being emptied, the cold converter was blown down to atmospheric pressure. Low pressure liquid oxygen was then added to the cold converter to the level of a calibrated try-cock. The amount of oxygen added was determined by the known volume of the cold converter when filled to the calibrated try-cock level. In order to maintain continuity of pipeline operation, it was, of course, necessary that at least two cold converters be installed at each customer's cold converter installation.

- By means of manometer type liquid level gauges on the customer's low pressure storage tanks.

• By weighing the liquid oxygen trucks before and after making deliveries into customers' low pressure storage tanks.

Satisfactory accuracy was obtainable when the above methods were operated correctly. However, all three methods were expensive due to the large investments required and the time, labor, and loss of oxygen involved in the delivery of the oxygen.

PROPERTIES OF LIQUID OXYGEN AND NITROGEN

The problems inherent in the design for service at cryogenic temperature can be appreciated by comparing the properties of liquid oxygen and nitrogen with those of water. (Exhibit A-1)

The extremely low operating temperature of -320°F made it impossible to use any liquid lubricant on the parts of the meter subject to such a temperature.

Good Charpy impact values at low temperatures were required for the metal parts. Thus, the preferred metals would be brass, bronze, stainless steel or aluminum.

The 410°F temperature drop from room to operating temperature would reduce the dimensions of metal parts by 0.004" per inch and must be considered in the design to provide proper clearances.

In order to minimize the amount of expensive low temperature refrigeration required to cool-down the meter and for heat leak during operation, it was necessary that the meter be lightweight and compact.

The large ratios of gas to liquid volume - 862 for oxygen and 693 for nitrogen - made it imperative that no gas be passed through the meter. A very small amount of liquid vaporization before or inside the meter would adversely affect the meter accuracy by making it read fast. Gas passing through the meter might speed up the moving parts enough to damage them.

The large change of density of the cryogenic liquids due to temperature changes placed another limitation on the design of the meter. The operating temperature range of individual liquid oxygen or liguid oxygen meters had to be limited in order to help assure meter accuracy. Temperature compensation would greatly complicate the meter design.

The low specific heats of the cryogenic liquids made it more difficult to control the temperatures of the metered liquids.

The low viscosities of the cryogenic liquids would increase the leakage through the clearances of the metering elements. Clearances had to be minimized to reduce the adverse effect of leakage on the accuracy of the meter at low flow rates.

The metering of liquid oxygen placed another vital safety requirement on the design of the meter. Combustible materials, which might come in contact with gaseous or liquid oxygen, must not be used in the meter. Oxygen combines easily and sometimes with explosive violence with even minute amounts of combustible material.

"CADILLAC" METER

In 1939 Peter M. Reide and Anton E. Hittl of the Linde Tonawanda Laboratory undertook the problem of developing an improved liquid oxygen meter by modifying a "Cadillac" steam condensate meter to make it suitable for liquid oxygen metering. (Exhibit A-2) Reide had his MSME from the University of Minnesota and had been with Linde a little over a year. Hittl was an MIT graduate with an MSCE and had been with Linde about 2 years.

The meter which they modified had a rated capacity of 12,000 lbs. per hour of water which corresponded to 23 gpm of liquid oxygen. It weighed about 200 lbs.; its overall dimensions were 30" x 30" x 30" and the working pressure was 15 psi.

The meter consisted of a rotating copper drum within a pressure tight casing. The drum was divided by partitions into compartments in such a way that liquid falling into the lower compartment caused the drum to rotate. The rotation of the drum was measured by the counter mechanism. The meter measured liquid only and would not register any gas that might pass through it.

They made several modifications to the meter:

a. They installed soft gaskets suitable for oxygen service.
b. They installed a low heat leak extension for the counter mechanism and shaft to permit operation at atmospheric temperature.
c. They improved the bearings.
d. They eliminated all materials not suitable for oxygen service.
e. They enlarged the liquid and gas lines between the meter and customer's storage tank.
f. They insulated the meter and connections.

After several months of testing, during which the amount of liquid oxygen registered by the meters was weighed by accurate scales, it was concluded that the meter measured liquid oxygen satisfactorily and accurately (less than ±1% error).

Thus the "Cadillac" meter provided a solution for the problem of metering liquid oxygen delivered into customers' storage tanks which operated at less than 15 psi pressure. About 10 installations were made.

The "Cadillac" meter could not be modified to make it suitable to meter liquid oxygen into cold converters operating at 150 psi pressure. Furthermore, it was not suitable for installation on trucks as it was bulky and heavy.

OSCILLATING PISTON AND NUTATING PLATE METERS

During 1941 Russell M. Thayer, a graduate of the University of Minnesota, and Mr. Edward F. Dandrow, BSME from MIT, of the Linde Tonawanda Laboratory looked into the feasibility of adopting commercial water meters for use as liquid oxygen meters. Two types of meters were tested. Each had a capacity of about 10 gpm, weighed less than 25 pounds, and required little space.

The National oscillating piston meter (Exhibit A-3) had a hollow cylinder (the piston) moving in an eccentric circular path in a chamber of appreciably larger diameter. A division plate extended from the chamber into the piston and divided the chamber outside of the piston into two separate parts. As the piston moved it produced a positive displacement which was used for metering. A shaft attached to the piston transmitted its motion through gears onto a register.

In the Pittsburgh nutating plate meter, (Exhibit A-3) a plate which is clasped between two hemispheres was installed in a measuring chamber. An axial shaft was attached to the plate, which was placed in the measuring chamber so that the shaft was inclined at an angle of several degrees from the center line of the meter. The top of the shaft meshed with a bevel gear which transmitted the motion of the plate onto the register. The flow of liquid caused the plate to nutate in the chamber to measure displacement volume.

Modifications were made to each type of water meter. The original rubber parts were changed to parts made of bonded graphite. Clearances were increased. The registers and shaft packing were installed at the end of low conductivity extensions which permitted them to operate at atmospheric temperatures. The meters were cleaned for oxygen service.

The meters were tested with water and with liquid oxygen. Liquid oxygen was pumped from a low pressure storage tank through the meter, which was immersed in an open trough filled with liquid nitrogen to precool the meter, and finally discharged into a cold converter. The converter was mounted on accurate scales so that the metered liquid could be weighed as a check on the registration of the meters. Instruments were provided to measure the temperatures and pressures before and after the meter and at other important points.

After about a year's test work which included many modifications to the meters, the Pittsburgh nutating plate meter showed the great promise of eventually becoming suitable for metering liquid oxygen. However, it was obvious that considerable development work would be required. There was rapid and excessive wear on the sealing and moving parts which increased the meter error to undesirable values. The pressure drop was high. The tests also demonstrated that it was essential that the meters be thoroughly cooled prior to use and that no gas pass through the meters during operation.

20 G. P. M. IMO METER

Late in 1941 Thayer and Dandrow started investigation of still another meter. They visited the Pittsburgh offices of Pittsburgh Equitable Meter Company and discussed with their chief Engineer, Mr. Carlin, the construction and characteristics of their Imo meter and the feasibility of modifying and using it to meter liquid oxygen.

The word "Imo" was derived from a portion of the firm name, "Aktie Bolaget Imo Industri", of Stockholm, Sweden. That company had developed the water meter which was probably a fallout of the development of liquid pumps which used power driven intermeshing rotors to pump liquids. In 1938 the Pittsburgh Equitable Meter Company had obtained the American rights to build and sell the Imo meter.

The major features claimed for the meter were that its error was within ± 1/2% between 100% and 2% of capacity and that it almost literally measured drops of water. The pressure drop was low, the operation of the rotors provided a smooth, pulsation-free metering action which minimized friction loads and wear. It was compact and light in weight.

Because of the above features, especially the smooth pulsation-free metering action of the revolving rotors, Mr. Thayer believed that the Imo meter had better operating characteristics. Also, it would be easier to modify and maintain

in liquid oxygen service than any of the other meters tested previously. A 50 gpm and a 20 gpm water meter were available. One of the latter was purchased and brought back to the Linde Laboratory at Tonawanda, New York.

Exhibit A-4 shows the construction of an Imo meter after conversion to oxygen service. The metering mechanism consists of three deeply grooved interlocking rotors which are closely fitted inside a brass measuring chamber. The helical channels in the rotors are of a special contour such that a line seal is obtained where the rotors mesh. Liquid passing up through the measuring chamber causes the rotor to turn. Each turn of the rotors passes a fixed volume of liquid. The center or "power" rotor carries a gear pressed into its top which transmits rotation through reduction gears and spindle to the meter register. At full capacity the rotors revolve about 4,000 rpm.

The 20 gpm Imo water meter was modified for liquid oxygen service. Only the minimum number of changes were made as the main objective was to quickly and economically determine the feasibility of using the Imo meter for metering liquid oxygen. The meter was provided with a copper cooling jacket. The original rubber rotors were replaced by rotors made of a bonded graphite which was self-lubricating and suitable for oxygen service. Mr. John Cox of the Linde Factory toolroom machined helices in the bonded graphite rotors using the rubber rotors as a model. Previous experience with machining the bonded graphite was used as such materials were quite fragile and required special cutting tools, speeds and other techniques. The original rubber or metal bearings for the reduction gears and spindle (register drive shaft) which operated in liquid or gaseous oxygen, were replaced by bearings made of bonded graphite. An extension piece of low conductivity material (Everdur) and stainless steel spindle were provided to permit operating the meter register and spindle packing at atmospheric temperature. (The meter register and spindle packing of the original water meter were directly above and close to the reduction gears and would not operate satisfactorily at liquid oxygen temperatures.) No changes were made in the number or arrangement of gears in the reduction gear box, the change gears, or in the standard gallon meter register.

Thayer and Dandrow modified the meter for liquid oxygen service, installed and tested it in the Linde Laboratory liquid pump-meter test installations at Tonawanda, New York. During a thirty day period about 45,000 gallons of liquid oxygen were metered at rates varying between 8 and 15 gpm. Both rotary and reciprocating liquid oxygen pumps were used. The accuracy was 95% which varied only slightly during the test period. There was only slight wear of the rotors.

<u>50 G.P.M. IMO METER</u>

The operation of the 20 gpm Imo meter was so encouraging that several 50 gpm meters were purchased, modified, and tested with liquid oxygen. The test program included operation at high and low capacities, use of rotors machined at Tonawanda and by the Pittsburgh Equitable Meter Company. Dimensions and clearances at vital points of the meter had to be varied to determine the preferred values.

The following examples demonstrate the nature of the changes.

The coefficient of linear expansion of the bonded graphite rotor is about 8% of the coefficient of the brass used for the meter measuring chamber. As mentioned earlier, the 410° temperature drop from room temperature would reduce the dimensions of the brass parts by 0.004" per inch. In order to avoid binding of the two parts during cool-down through the temperature range of 410°F. it was necessary to make the diameter of the larger (1-1/2" D.) rotor at least 0.0055 inches smaller than the diameter of the space in the measuring chamber in which it rotates. (1.5 x 0.004 x (100-8) = 0.0055). If excessive clearances were provided, the accuracy of the meter was decreased and the minimum flow rate for accurate metering was increased. The diametrical clearances actually provided were 0.008 inches minimum and 0.016 inches maximum. The larger clearances were provided for running clearances and to allow for manufacturing tolerances.

To assure proper meshing of the gears after cool-down, it was necessary to make the 4-1/2 inch long 1-1/2 inch diameter rotor-pinion gear assembly 0.018 inches shorter for liquid oxygen than for water service.

The meter test program demonstrated low pressure drops through the meters; there was negligible wear of the rotors and satisfactory meter accuracies were obtained and maintained (error within ±2%) under test conditions.

The meter tests also provided information as to which gears were required to obtain the desired registration units. The Imo water meters were provided with registers which read in gallon units and were provided with a sweep hand which measured one gallon per revolution, as was customary for such service. Liquid oxygen is usually metered and sold in units of 100 C.F. of gas equivalent at N.T.P.* conditions. It was

* N.T.P. - normal temperature and pressure: 70°F and 760 mm Hg absolute pressure.

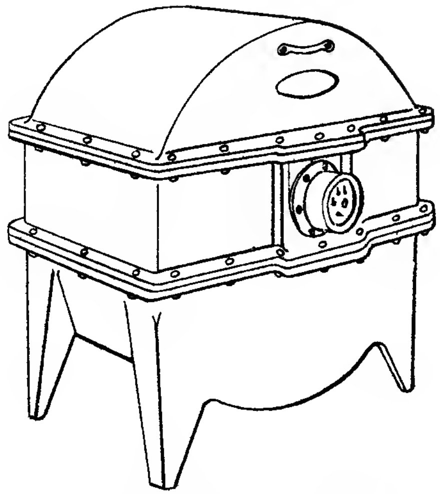
specified that the liquid oxygen meter register such units. That created one more problem as the specified registration represented a definite weight but a variable volume of liquid oxygen. The volume was dependent on the temperature of liquid being metered. The density of liquid oxygen decreases about 2.8% when its temperature increases 10°F.

From the results of many, many tests, both at the Laboratory test installation and in the field, it was determined that liquid oxygen which is initially at atmospheric pressure will be warmed up about 9°F. to a temperature of -288°F. by the work of pumping and heat leak into the system. The specific volume of liquid oxygen at the metering temperature of -288°F is 0.01436 cu. ft. per pound. The change gears of the meter were then determined using that value to obtain the specified registration units of 100 C. F. of oxygen gas. As one gallon of liquid oxygen at the specified volume would be equivalent to 112 C. F. of oxygen gas at N.T.P. conditions, it was only necessary to provide change gears which would slow the standard gallon register by the ratio of 100:112. No gear changes were made in the standard gallon register or reduction gear assemblies.

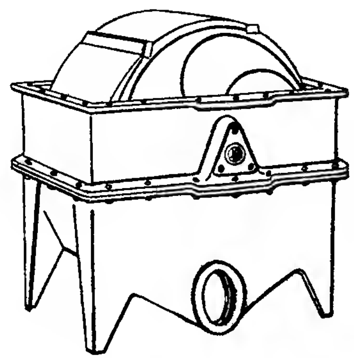
By the end of 1942 it was evident to Russell Thayer and Linde Management that although all problems had not been solved and new ones might develop, the Imo meter would be suitable for metering liquid oxygen and for billing Linde customers. A design and specifications were developed and an order was placed with the Pittsburgh Equitable Meter Company to build 100 liquid oxygen meters. The 50 gpm meter was about 5 inches in diameter, about 16 inches high, and weighed about 35 pounds. Exhibit A-5 shows the components of the 50 gpm meter.

At this time the Instrument Department of Linde's Tonawanda Laborabory, which was headed by Mr. George Kellner, who had been with Linde for over 14 years was brought into the picture. That department was to be given the responsibility for calibrating the Imo meters with liquid oxygen, repairing them, and rebuilding them as required.

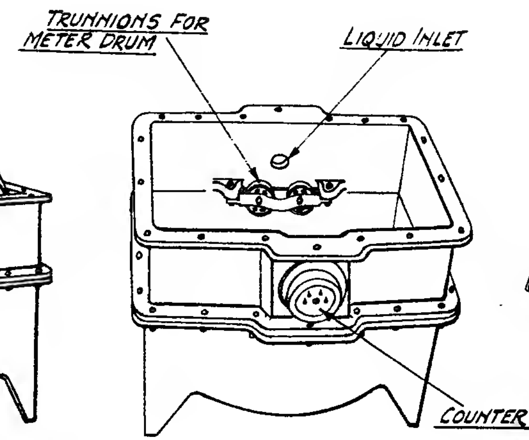
During this period the liquid oxygen meters were also used to meter liquid nitrogen after changes were made in the change gears to obtain the desired registration units. Many of the liquid nitrogen meters were specified to register directly in gallons of liquid nitrogen. For other meters, when it was specified that the meter register in units of 100 C.F. of nitrogen at N.T.P. conditions and the temperature of the metered liquid nitrogen was -310°F. (10°F. warmer than the -320°F normal boiling point), it was necessary to provide change gears which would speed up the



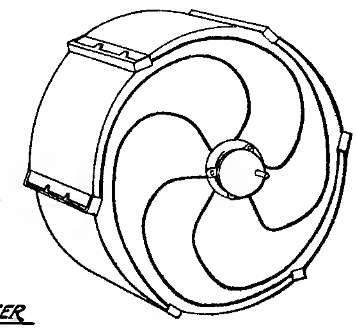
OUTSIDE VIEW OF METER
(FRONT)



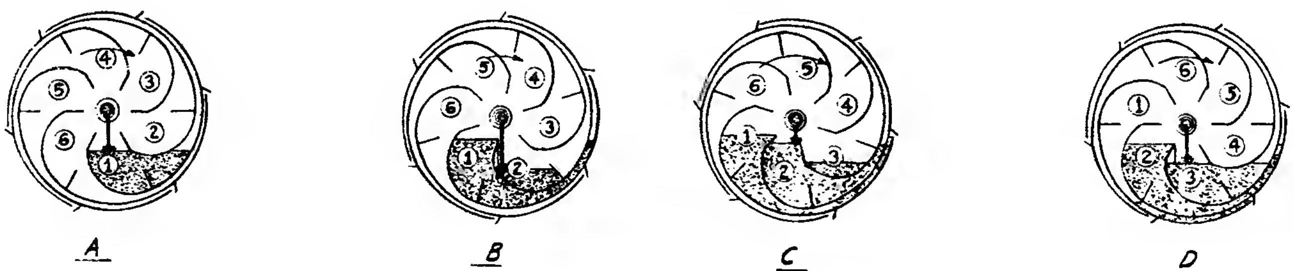
METER WITH COVER REMOVED
(BACK VIEW)



METER WITH DRUM REMOVED
(FRONT VIEW)



METER DRUM



DIAGRAMS SHOWING PRINCIPLE OF OPERATION OF METER

"CADILLAC" CONDENSATION METER

EXHIBIT A-2

standard gallon register by the ratio of 100:89.6 . One gallon of liquid nitrogen at -310°F. would be equivalent to 89.6 C.F. of gaseous nitrogen at N.T.P. conditions. No gear changes were made in the standard gallon register or reduction gear assemblies.

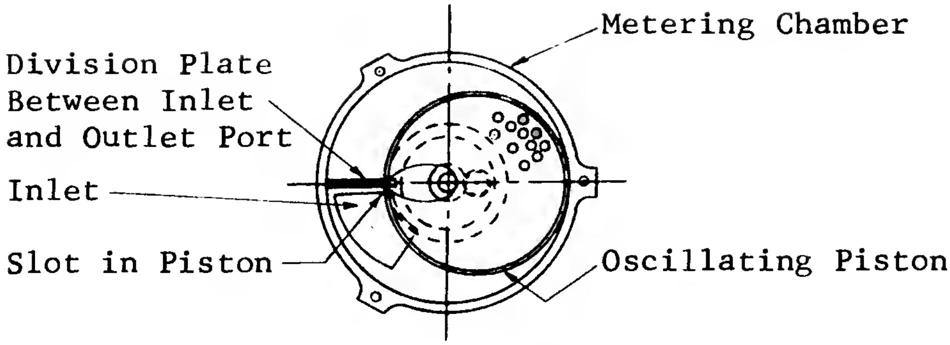
PHYSICAL PROPERTIES OF OXYGEN, NITROGEN, WATER

	OXYGEN	NITROGEN	WATER*
Boiling Point (1 atm.) °F	-297	-320	
Liquid Density			
At Boiling Point - lb/cu.ft.	71.3	50.5	62.4
Decrease in Density per 10° F Increase in Temp. above Boiling Point - %	2.8	3.4	0.1
Gas Density - N.T.P.-lb/cu.ft.	0.0827	0.0724	
Ratio - $\frac{\text{C.F. gas N.T.P.}}{\text{C.F. liquid B.P.}}$	862	693	
Heat of Vaporization			
B.t.u./lb. at B.P.	91.7	85.2	
B.t.u./C.F. at B.P.	6550	4300	
Specific Heat of Liquid - B.t.u./lb.°F	.41	.49	1.0
Viscosity of Liquid at B.P.-lb./hr.ft.	.46	.38	2.4

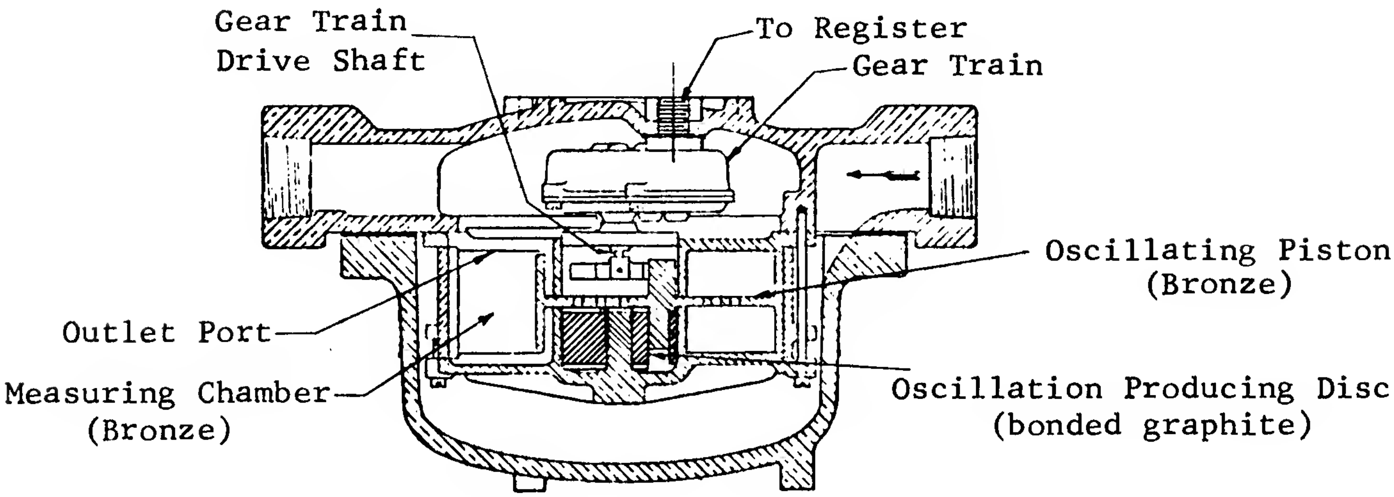
N.T.P. - normal temperature and pressure: 70°F and 760 mm Hg absolute pressure

*All values referring to Water are based on a water temperature of 70°F.

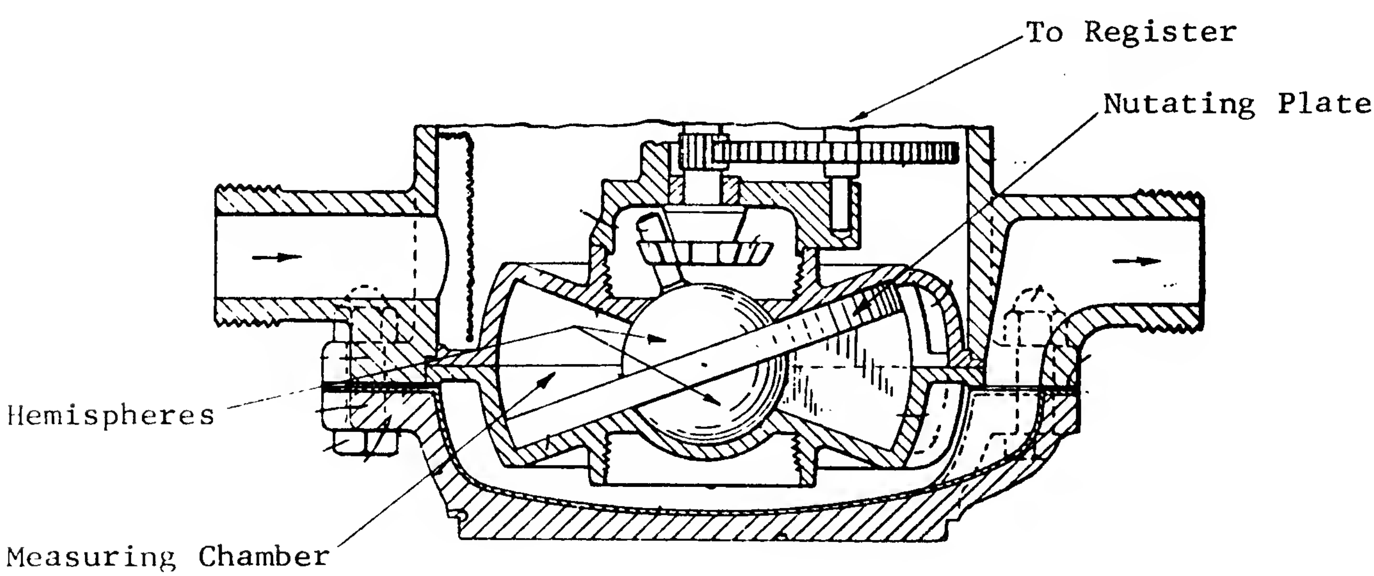
EXHIBIT A-1



PLAN VIEW OF METERING CHAMBER
WITH TOP SEALING PLATE REMOVED

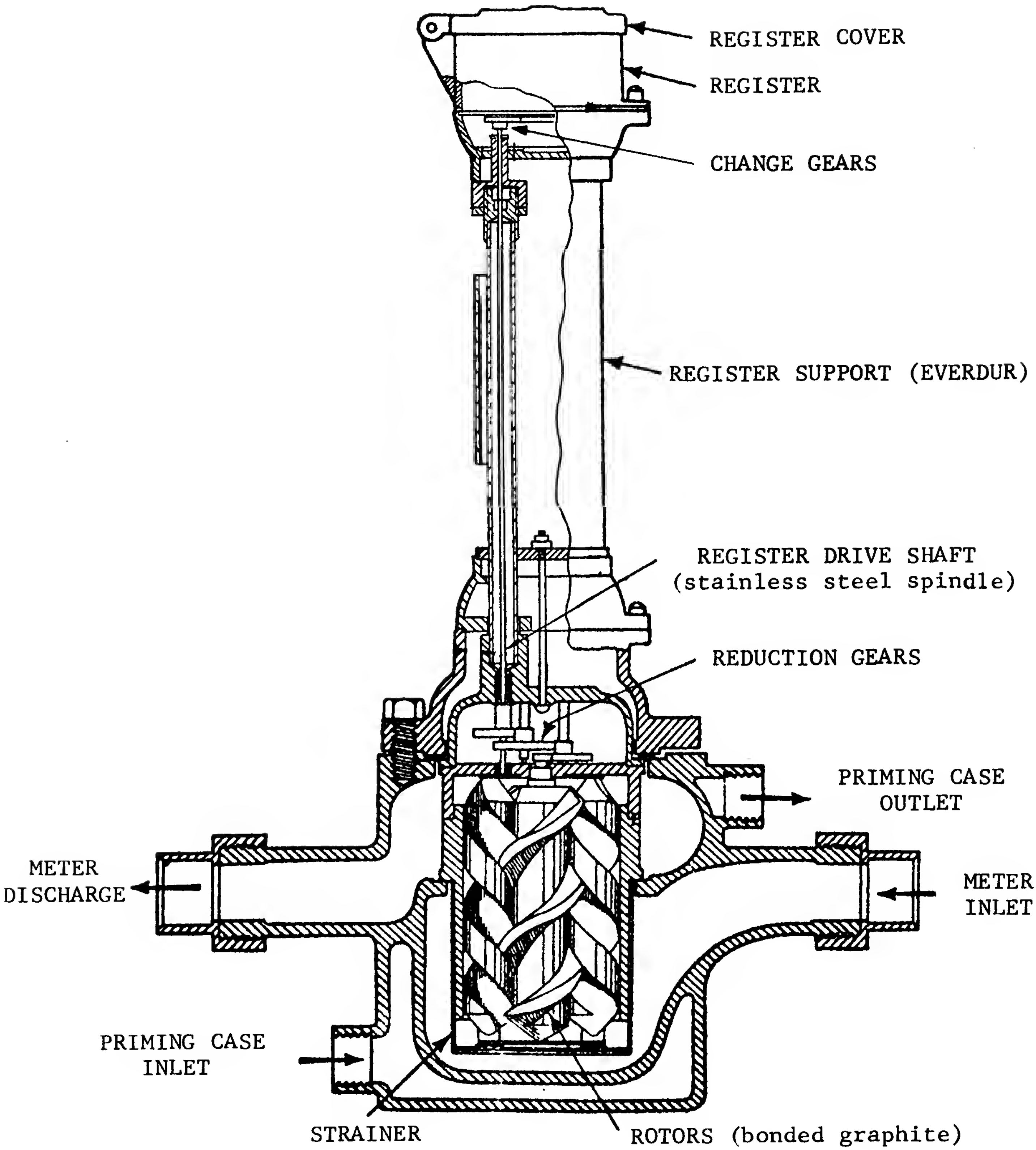


OSCILLATING PISTON METER



NUTATING PLATE METER

EXHIBIT A-3



IMO LIQUID METER

EXHIBIT A-4

IMO METER PARTS

EXHIBIT A-5

THE CRYOGENIC METER (B)

PROBLEMS WITH 50 G.P.M. METERS

It had been planned that the liquid meters would be returned to the Linde Instrument Department at Tonawanda, New York, once a year for a check on the accuracy of each meter. It had been hoped that the meters would operate for several years before needing repairs.

However, within a year after the meters were placed in operation it became evident that there were serious problems with them - especially those which had been mounted on trucks or were metering liquid nitrogen. Meters were returned because they were inoperable or were greatly out of calibration.

The inoperable meters had generally been installed on trucks. The gears and register mechanism could not withstand the vibration of truck travel which literally wore out spindles, bearings, gears and registers. Eventually some of these parts jammed and prevented the meter from turning. In some cases the meter spindles were twisted.

It was necessary to redesign to better withstand the vibrations from truck travel and vicissitudes of meter operation.

- The registers on all meters were lubricated with an oxygen-compatible lubricant to help prevent jamming of the mechanism.

- The dial glass of the registers was cemented in place to prevent the glass from chipping under vibrating conditions which jammed the register.

- The screws holding the registers together were cemented in place to prevent their coming loose.

- The connection between the change gear and the spindle was strengthened by the addition of a second key.

- All meter shipments were made in a special container designed to prevent damage of the meters in transit.

- To prevent galling of the spindle at the bottom of the packing box, the clearance hole was enlarged and a bonded graphite bushing was provided at that location.

• The plate on the bottom of the metering chamber was substantially cut away to reduce the pressure drop through the meter.

• The screen around the measuring chamber was fastened more securely to the measuring chamber to prevent foreign material from entering the meter mechanism.

• A thicker flange was provided to prevent distortion under bolt loads.

• The strength of the press fit of the 8-tooth pinion gear in the top of the bonded graphite power rotor was checked on each meter to prevent a weak joint from being placed in service.

• The gear arrangement inside the 2-3/4" diameter x 1" deep reduction gear box assembly was simplified. Originally, for oxygen meters, motion was transmitted to the register by means of a 53-tooth gear on the top of the spindle which meshed with and drove an 11-tooth gear on the register shaft. Because of the relatively large diameter of the gear on the spindle, any slight wobbling of the spindle was magnified at the periphery of the gear and caused excessive wear of the gears. In a gear train of this type, good practice required a small gear driving a large gear, or nearly equal gears, if possible. By eliminating one of the three 8-32 tooth pinion assemblies inside the reduction gear box, the speed ratios were changed so that 34-tooth and 30-tooth change gears were required in place of the original 53-tooth, 11-tooth combination.

The new gear arrangement thus became the 8-tooth pinion gear on the 1-1/2"D. power rotor, which drove in series two 8-32 tooth pinion assemblies (the third assembly had been eliminated) which in turn drove a 32-tooth gear fastened to the bottom of the 1/8"D. stainless steel spindle. With the new gear arrangement the spindle revolved at 1.56% of the speed of the power rotor and the register shaft revolved at 1.78% of the speed of the power rotor.

• The elimination of the third 8-32 tooth pinion assembly reversed the direction of rotation of the spindle and register drive shaft. This was compensated for by using a left handed worm gear in place of the orignial right handed worm gear to drive the counter wheels of the register.

• Greater care was taken in installing and aligning the meter as there was some evidence that misalignment caused binding which increased the wear on all meter parts including the oxygen meter rotors.

The meters which were out of calibration were generally running slow because of excessive wear of the rotors. The bonded graphite, which had been satisfactory when used for the rotors of the liquid oxygen meters, wore very rapidly when used in liquid nitrogen service. The wear on the 1-1/2" diameter power rotor could be measured in not thousandths but fractions of an inch, and in some cases the meter registration was 10 to 30% slower after only a few hours' service. It was evident that the nitrogen meters were a disaster.

Investigations showed that the rapid wear of the rotors in nitrogen service could not be explained by any obvious reason such as greater rubbing speeds, greater bearing loads or the use of bonded graphite incorrectly formulated or manufactured. Mr. V. C. Hamister of the National Carbon Company, a Division of Union Carbide Corporation, was finally contacted. He explained that the bonded graphite had shown very little wear in oxygen service because the oxygen had formed a molecular film on the graphite surface which acted as a dry lubricant and minimized wear.

However, a molecular oxygen film could not be maintained when metering liquid nitrogen which contained less than 10 parts per million of oxygen. Hence the high rate of wear in nitrogen service. He stated that some carbon brushes of electric motors also experienced rapid wear when used in a high vacuum or at very high altitudes.

Mr. Hamister advised testing other compositions of bonded graphite with various impregnations. Such materials might form and maintain suitable lubricating surface films.

Over 25 different materials were tried in bench tests and in actual meters. These included such materials as aluminum, plastics, wood and many formulations of bonded graphite with various impregnations. A new bonded graphite suitably impregnated was finally obtained which had minimum wear (about the same rate of wear as the original graphite in oxygen meters) and machining and mechanical properties which made it suitable for use in liquid nitrogen service.

From the field experience it was apparent that operating personnel required additional training on the methods for installing and operating the meters. An appreciable number of meters had been over-speeded by allowing gas to pass through them.

By 1945 the metering problems had been identified, solutions were available and were being implemented as quickly as possible. All liquefied gases produced and sold by Linde were

being billed by means of the Imo cryogenic meter. The responsibility and work connected with the Imo meter was consolidated in the Instrument Department under the supervision of George Kellner. This included building the meters from parts furnished by the Pittsburgh Equitable Meter Company, improving, repairing, and calibrating the meters.

THE CRYOGENIC METER (C)

DEVELOPMENT OF METERING SYSTEMS AND APPLICATIONS

Russell Thayer and his associates found that their task was not limited to modifying and developing the liquid oxygen meter. They found that it was necessary to develop a metering system as part of the development program. Since extremely volatile liquids were to be metered at temperatures as low as -320°F., it was essential that most of the meter development work should be accomplished in an environment and system very similar to actual operating conditions.

Exhibit C-1 shows the preferred system and flow arrangement for pumping liquid from a truck, through an Imo liquid meter into a customer's cold converter (i.e., his storage tanks) while it is being operated at pipeline pressure, usually at 150 psi or higher pressure.

The flexible connection is first installed between the truck discharge connection and the cold converter filling connection. Cold converter pressure is then applied to the filling connections putting about 150 psi pressure against the spring loaded check valve just past the meter. The liquid pump is cooled by opening the pump suction and priming valves. This also partially cools the meter. The liquid pump is started which circulates liquid through the meter jacket and returns it to the truck liquid container. This thoroughly cools the meter and fills it with subcooled liquid. The pump priming valve is then closed thereby increasing the pump and meter pressures sufficiently to open the spring-loaded check valve and discharge metered liquid oxygen into the cold converter. After the required amount of liquid has been delivered, the pump priming valve is opened, the pump shut down and after a few minutes the flexible connection is disconnected. The amount of oxygen delivered is determined by the difference in meter reading before the pump is started and after it is shut down.

No reverse registration of the meter or excessive forward registration due to gas passing through the meter occurs when the above procedures are carefully followed.

It is important that the meter is installed in the pump discharge line to the cold converter, but the meter jacket is connected to the pump priming line <u>after</u> the priming valve. The piping is as short and simple as possible. It is essential that a spring-loaded check valve be connected <u>next to</u>

the meter discharge connection. These important features of the metering system were not provided by happenstance. They were determined as the result of many months of planning, testing and operation.

As an example of how these decisions came about, the installation of a <u>spring-loaded</u> <u>check</u> <u>valve</u> <u>next</u> <u>to</u> the meter discharge connection was one of the most controversial features as it involved both technical considerations and personalities.

During the initial meter testing at Linde's Tonawanda Laboratory, a check valve was not provided but a manual valve was installed about one foot downstream of the meter. It was necessary to simultaneously manipulate both the meter discharge valve and the pump priming valve to place the pump and meter in service. Thayer and his associates quickly learned that it was necessary to relocate the meter discharge valve <u>next to</u> and as <u>close to</u> the meter as possible. The original one foot section of piping between the meter and valve allowed a slug of gas to pass through the meter during cooldown. That resulted in a false high meter reading. When the pump and meter were shut down the residual liquid in the one foot pipe section evaporated, gas passed backwards through the meter and reduced the amount registered. With the meter discharge valve close to the meter, there was no forward or backward gas spinning of the meter when both valves were operated correctly.

In order to simplify the system, Thayer and Dandrow replaced the <u>manual</u> meter discharge valve with a <u>check</u> valve in the Laboratory meter installation. This accomplished its purpose when the metered liquid was discharged into receiving vessels under at least 25 psi pressure. At lower pressures the pump discharge and meter pressures were so low that at times some of the liquid flashed into gas. This resulted in erroneous meter registrations when gas slugs passed through the meter. Thayer's solution to the problem was to install a <u>spring-loaded</u> chack valve. The spring-loaded check valve accomplished the purpose of simplifying the system and assuring satisfactory meter accuracy.

However, when Thayer and Dandrow's metering system was reviewed with the Production Department prior to the first test installation at a customer's installation, several Production Department supervisors objected to the installation of the spring-loaded check valve and requested that it be replaced with a manual valve.

The Production Department had a legitimate criticism, since the spring-loaded check valve increased the pump discharge pressure, it also decreased the pump capacity and increased

labor time and costs for pumping and transferring liquid. The initial installations were made with the manual discharge valves. Operating experience soon required a change to the spring-loaded check valves. It was preferable to pay for the somewhat higher pump discharge pressures in order to obtain a simpler and more accurate metering system. Actually, the higher pump discharge pressure decreased pump capacity only a small amount since turbine type liquid oxygen pumps were being used.

At one of the first test installations of the system for pumping and metering liquid directly into cold converters at pipeline pressure, Ed Dandrow installed a liquid oxygen pump and meter on a liquid oxygen truck for test. The piping arrangement was similar to that shown in Exhibit C-1 except that a manual shut-off valve was used in place of the check valve after the meter.

In order to simulate the delivery of metered liquid from a Linde truck into a customer's cold converter, liquid oxygen was pumped from the test truck into the test cold converter installed at the Laboratory liquid pump-meter test facility. After making several satisfactory metered deliveries at the test facility, Dandrow arranged that a metered liquid oxygen delivery be made from the test truck, which was operated by its regular driver, Perry Beyer.

After connecting the liquid truck to the cold converter and following satisfactory laboratory procedures, the truck liquid pump was started and the meter was cooled.

Suddenly, while the pump discharge pressure was being increased by closing the pump priming valve, a huge cloud of white powdered insulation and oxygen was discharged from the insulation space of the cold converter. Dandrow and Beyer were startled for it seemed an explosion had occurred. This was a sensitive situation as they were making the test in a vital war plant during the war.

After the liquid pump was shut down and the dust had settled, investigation showed that the cold converter filling line had broken between the filling valve and filling flange. This allowed liquid oxygen to discharge into the insulation space from which it escaped blowing out large quantities of insulation.

Apparently, that section of the filling line had become badly twisted and weakened from making the filling connections during many years of service. The twisted section, which normally operated at atmospheric pressure, failed when pump discharge pressure was applied to it.

As a result of this experience and other tests, the system confirmed the inclusion of a spring-loaded valve after the liquid meter. Operating procedures were changed to specify that cold converter pressure must be applied to the filling connections before starting the pump.

The above incident helped prove the point that one field test may be worth several Laboratory tests.

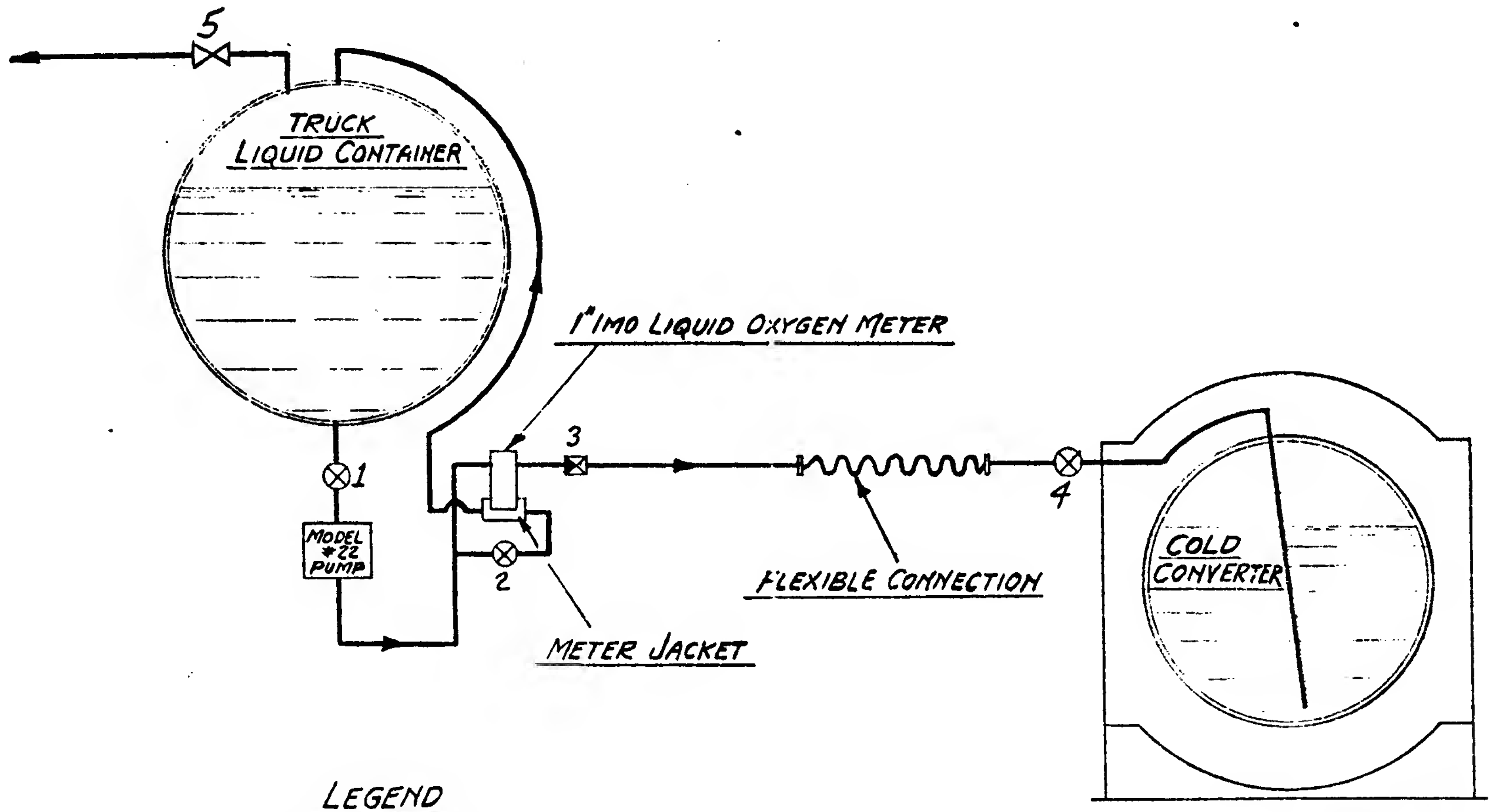
During 1943 liquid pumps and meters capable of pumping to pressures of over 200 psi were installed on most of Linde's liquid oxygen and nitrogen trucks. Cold converters were filled under pressure and the Imo meters were used for billing customers.

There were also meter installations in low pressure applications in which a low pressure liquid oxygen pump and meter were piped together and installed as a stationary ground mounted unit. Liquid oxygen was pumped from a low pressure tank car or truck into a low pressure storage tank. The meter was cooled to operating temperature by first circulating liquid through the meter jacket. The discharge pressure of the pump and meter were artificially maintained at 50 psi by means of a spring-loaded check valve in order to assure that only subcooled liquid oxygen would be metered.

Liquid oxygen as produced in air separation plants was also measured by the Imo meter. Liquid pumping was not used to achieve subcooling of the liquid. The necessary subcooling required for metering liquid oxygen production was obtained by withdrawing liquid oxygen from the condenser of the air separation unit and piping it down to the meter which was located at ground level. The 20 foot drop subcooled the liquid oxygen sufficiently for metering.

SYSTEM FOR CALIBRATING METERS

Since it was planned that each of the Imo meters used for billing customers would be returned to the Linde Instrument Department once a year to determine its calibration, it was necessary to set up a method for such calibrations. This consisted of a low pressure storage tank, a liquid pump, and a cold converter mounted on scales, all of which were installed inside a building. The piping arrangement was similar to that shown in appended Exhibit C-1 but with the added feature that liquid from the cold converter could be returned to the storage tank for re-use. Calibrated test thermocouples and pressure gages were installed at strategic points.



LEGEND

1.- SUCTION VALVE TO PUMP
2.- PRIMING VALVE OF METER & TRUCK
3.- CHECK VALVE ON DOWNSTREAM SIDE OF METER
4.- CONVERTER LIQUID FILLING VALVE
5.- TRUCK LIQUID CONTAINER GAS PHASE BLOWDOWN VALVE

TITLE: FLOW DIAGRAM OF PIPING WITH 1" IMO METER INSTALLED ON MOBILE UNIT

EXHIBIT C-1

Liquid was pumped from storage through the meter into the cold converter on the scale. No gas was vented during calibration. The liquid lines were filled before calibration started, the flow was stopped momentarily to read the scale statically, and then the test was conducted. The static scale reading was taken at the conclusion of the test. The scale was accurate to within ± .1% which was the maintenance tolerance. Temperature of the liquid was measured within 0.14°C. so that the specific volume was correct within 0.084%. Total system uncertainty was less than 0.25%. Liquid oxygen was used to calibrate the Imo meters.

Records were maintained of the calibration test of each meter. When requested, customers of interested governmental agencies were given access to records and were permitted to observe the calibration procedures.

Each meter shipped from the Instrument Department was accurate to within ±1%.